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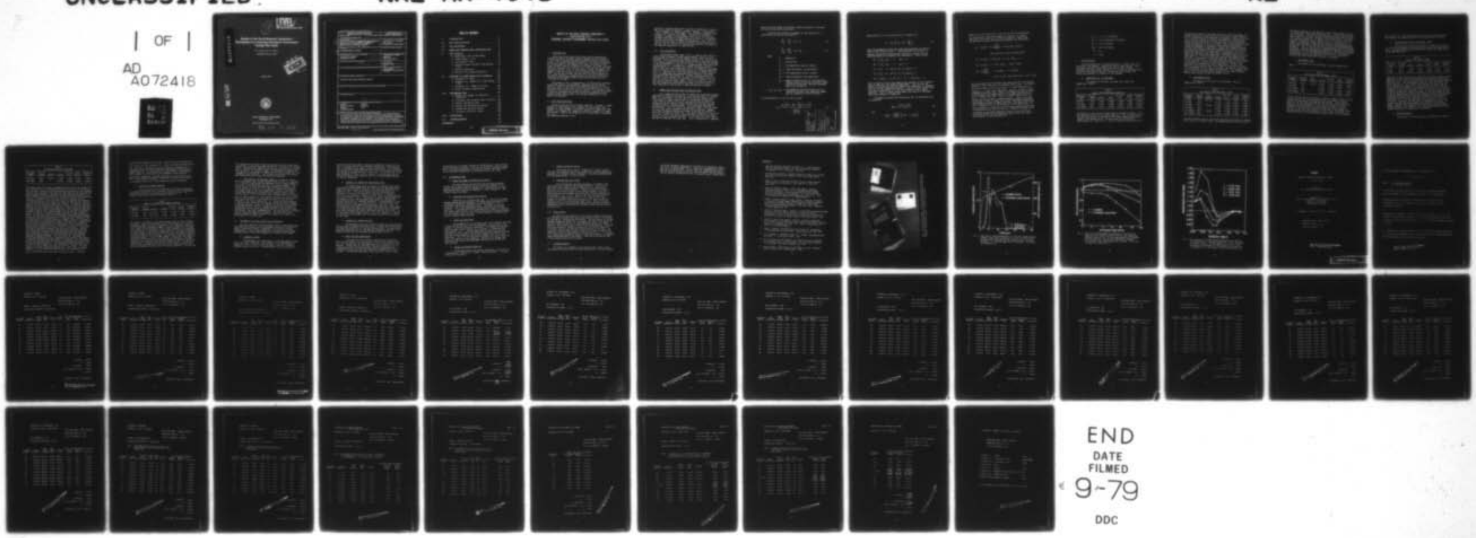

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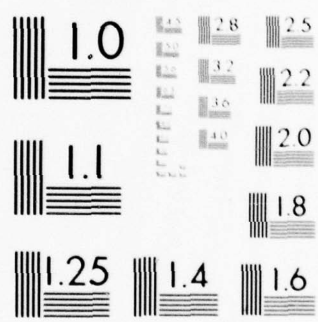
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LEVEL II

NRL Memorandum Report 4048

Results of the Naval Research Laboratory's Participation in a Personnel Dosimetry Performance Testing Pilot Study

R. B. LUERSEN AND T. L. JOHNSON

Radiological Protection Staff

July 26, 1979

NAVAL RESEARCH LABORATORY
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The results of the Naval Research Laboratory's participation in a personnel performance testing pilot study are given. The study, sponsored by the U.S. Nuclear Regulatory Commission, was conducted by the Department of Environmental and Industrial Health, School of Public Health, the University of Michigan, Ann Arbor, Michigan. A brief description of the NRL badge, the calibration and readout procedures used, and the results obtained are included. Comments on the testing methods and procedures are given and recommendations are made for their improvement.

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RESULTS OF THE NAVAL RESEARCH LABORATORY'S PARTICIPATION IN A PERSONNEL DOSIMETRY PERFORMANCE TESTING PILOT STUDY

I. INTRODUCTION

During the period August 1978 to May 1979 the Radiological Protection Staff of the Naval Research Laboratory participated in a pilot study, Personnel Dosimetry Performance Testing, sponsored by the U. S. Nuclear Regulatory Commission. The test was conducted by the Department of Environmental and Industrial Health of the School of Public Health, University of Michigan, Ann Arbor, Michigan, under the direction of Dr. Philip Plato. The test was divided into two parts; Test No. 1 was for three months, August, September, and October, 1978; and Test No. 2 was for February, March, and April, 1979. The test was divided into two parts to give processors and the testing laboratory an opportunity to adjust their calibration techniques and procedures based on what was learned during the first part of the test.

The purpose of this correspondence is to describe the dosimeter used by NRL, some of the procedures employed, and the results obtained. Detailed calibration and reading procedures will not be given separately, rather what we feel are pertinent aspects will be included in the discussion of the test results. Also we make comments on the test procedures and methods and make recommendations which hopefully might improve them. The opinions expressed are solely those of the authors.

II. TEST PARTICIPATION

The tests were divided into eight categories: Category I, gamma; Category II, high-energy x ray; Category III, low-energy x ray; Category IV, beta; Category V, neutron; Category VI, gamma plus high-energy x ray; Category VII, gamma plus beta; and Category VII, gamma plus neutron. Some of the categories will be described in subsequent

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sections; a complete description is found in references (1) and (2). NRL participated in Category I (gamma), Category II (high energy x ray), Category III (low-energy x ray), Category V (neutron), and Category VIII (neutron plus gamma). We were also interested in Category VI (gamma plus high-energy x ray) but we felt that our dosimeter would have no trouble passing this test, if its performance was satisfactory for gamma and high-energy x rays. Also we did not have available sufficient dosimeters to participate in this portion. We will discuss the expected performance of our badge to the untested categories in a later section.

III. THE DOSIMETERS

The dosimeter badge, shown in Fig. 1, used for this test is a simple plastic (Harshaw) "folded cadmium design" similar to that described by Falk (3) using two cadmium filters 20 mm x 20 mm x 0.51 mm thick. This configuration was chosen because it provides the best x-ray energy response, ± 15% from 25 keV to 1.25 Mev when the average of the two detectors is used for x- or gamma-ray dose equivalent (DE) determinations (4). Although such "albedo" dosimeters normally require the use of two or more pairs of ^{6}Li-^{7}Li detectors, our badge uses a single pair of ^{6}LiF(TLD-600) detectors in a Harshaw Model N-6 card (5). The portions of the light output due to thermal neutrons and x- or gamma-rays are determined using essentially the method described by Nash and Johnson (6). However, because we have discovered (7) that fading of the TL peaks in LiF(TLD-600) is not the same for high-LET radiation (alphas from the n-α reaction in ^{6}Li as for low-LET radiation (beta, gamma, x rays) the equations used by Nash and Johnson were modified as described in the next section to more conveniently take account of these differences in fading.

IV. GAMMA AND NEUTRON DOSE DETERMINATIONS

Fig. 2 shows the glow curves for gamma rays and thermal neutrons obtained with TLD(600) N-6 detectors that have been read in a Harshaw Model 2271 automated TL analyzer using the heating schedule shown. This schedule, a rapid rise to 200^{o}C in two seconds followed by a linear rise to 330^{o}C at 5^{o}C/sec is used so that the portion of the glow curves due to neutron + gamma (0-250^{o}C) and that due neutrons (>250^{o}C) are easily differentiated. Two integrations were made on each detector. The first from 6 to 18 second ($\sim$200^o - 275^o) as shown in Fig. 2 was used to determine the dose due to neutrons + gammas. This lower integration period was chosen to minimize the effects of fading as described by Johnson (8). The second integration, from 20-25 sec ($\sim$285 - 310^{o}C), was used to determine what portion of the lower integral was due to thermal neutrons. In all cases the lower integral was used to determine the total dose. A third integration is sometimes

made from 28-30 seconds to determine reader background for low doses but was not used during these tests.

The doses from neutrons and gammas for each detector are determined by setting up two equations:

$$\frac{D_\gamma}{C_{\gamma L}} + \frac{D_n}{C_{nL}} = R_L - B_L \tag{1}$$

$$\frac{D_\gamma}{C_{\gamma H}} + \frac{D_n}{C_{nH}} = R_H - B_H \tag{2}$$

where

D_γ = gamma dose

D_n = neutron dose

R_L = low temperature reading, integral

B_L = reader background, low temperature

R_H = high temperature reading, integral

B_H = reader background, high temperature

$C_{\gamma L}$ = gamma correction factor for low temperature reading; product of fading correction, reader sensitivity correction, individual dosimeter sensitivity correction.

C_{nL}, $C_{\gamma H}$, C_{nH} = corresponding correction factors for low temperature neutron, high temperature gamma, and high temperature neutron readings.

Solving equations (1) and (2) for D_n we get:

$$D_n = \frac{C_{nH}\left[(R_H - B_H) - \frac{C_{\gamma L}}{C_{\gamma H}}(R_L - B_L)\right]}{1 - \frac{C_{nH}\,C_{\gamma L}}{C_{nL}\,C_{\gamma H}}} \tag{3}$$

Substituting (3) in (1) we solve for D_γ in terms of D_n

$$D_\gamma = C_{\gamma L} \left[(R_L - B_L) - \frac{D_n}{C_{nL}} \right] \tag{4}$$

Since the dosimeters usually have radiation backgrounds we subtract these to get the Net D_n and D_γ. These equations are solved by a computer program which makes several decisions to assure that the determined doses are reasonable and conservative. These include:

(a) If $(R_H - B_H) < 0$ set $= 0$

(b) If $(R_L - B_L) < 0$ set $= 0$

(c) If $D_\gamma < 0$ set $D_n = D_n + D_\gamma$ and $D_\gamma = 0$

(d) If $D_n < 10$ set $D_\gamma = D_\gamma + D_n$ and $D_n = 0$

(e) If $50\ D_n < D_\gamma$ set $D_\gamma = D_\gamma + D_n$ and $D_n = 0$

Test (a) and (b) do not allow negative net readings for the integrals. Test (c) does not allow negative gamma doses. This test has the effect of insuring that the total neutron plus gamma dose is dependent only on the lower temperature integral. Test (d) causes neutron doses less than the equivalent of 10 mR to be treated as due to gamma radiation. Test (e) causes neutron doses less than 2% of the gamma dose to be treated as a gamma dose.

The gamma and neutron dose equivalents (DE) are determined from the equations:

$$(DE)_\gamma = \frac{D_\gamma(F) + D_\gamma(R)}{2} \tag{5}$$

and

$$(DE)_n = K \frac{D_n(F)}{D_n(R)} \left[D_n(F) - J\ D_n(R) \right] \tag{6}$$

where $D_\gamma(F)$, $D_n(F)$ and $D_\gamma(R)$, $D_\gamma(R)$ refer to the calculated doses for the detector located with cadmium in front (F) or cadmium behind (R), and J and K are calibration constants. Again doses are adjusted to assure that they are reasonable and conservative:

(a) If $D_n(R) = 0$ or $\frac{D_n(F)}{D_n(R)} > 4$ set $D_n(R) = \frac{1}{4} D_n(F)$

and recalculate $D_\gamma(R)$ using new $D_n(R)$

(b) If $D_n(R) = 0$ and $D_n(F) = 0$ set $(DE)_n = 0$

(c) If $D_n(F) = 0$ set $D_\gamma(R) = D_\gamma(R) + D_n(R)$

(d) If $\frac{D_n(F)}{D_n(R)} < J$ set $(DE)_n = 0$ and set

$$D_\gamma(F) = D_\gamma(F) + D_n(F) \text{ and } D_\gamma(R) = D_\gamma(R) + D_n(R)$$

Test (a) assures that the neutron dose equivalent will not reach an abnormally large value due to an unusually small $D_n(R)$. Our studies have never shown a ratio of $D_n(F)/D_n(R) > 3$ under laboratory conditions or > 2 under field conditions. Test (b) is made to prevent attempted division by zero. Test (c) attributes the neutron signal of the detector with cadmium behind it to gamma radiation since $D_n(F) = 0$ makes $(DE)_n$ zero. Test (d) prevents negative $(DE)_n$ and assigns the neutron doses to gamma radiation. These latter tests assure that all the TL signal in the lower temperature integration is assigned to neutron or gamma radiation. Note that normally the $(DE)_\gamma$ is dependent only on the average of the two gamma doses. At very low energies a correction for shallow and deep dose equivalent is made based on the ratio $D_\gamma(F)/D_\gamma(R)$. Assuming the reader to be calibrated to read gamma radiation correctly and no individual correction factors for the detectors, typical values for some of the constants in these equations are:

$C_{\gamma L}$ = 1 (i.e., no fading)

C_{nL} = 1.15 (correction for fading)

$C_{\gamma H}$ = 178 (no fading)

C_{nH} = 14.0 (no fading)

J = 0.3

K = 0.86

V. TEST RESULTS

The test results for the second portion of the test, Test No. 2, are found in the Appendix. Because the results from Test No. 1 were considered to be more preliminary they have not been included (obviously they were worse); however, we will refer to them extensively during the discussion to follow. We have decided to discuss the results not necessarily grouped as in the Appendix.

A. Gamma Rays (30 - 10,000 mRem)

The results of the tests for gamma rays (Co-60) are summarized in Table 1.

Table 1
RESULTS FOR OCCUPATIONAL GAMMA RAYS

Dose Equiv. (mRem)	Ave. DE (mRem)	Source	P(Ave)	Std. Dev. (S)	Error /P/+2S	Allowable Error
30-100	68.6	Co-60	0.0863	0.0549	0.1962	0.7244
101-300	177.8	Co-60	0.1005	0.0488	0.1982	0.4500
301-10000	3010	Co-60	0.0993	0.0307	0.1607	0.3000

Examination of these results reveals several interesting points: First, our reported results are too high by about 10%. This is partly due to the fact that we made no corrections for fading (growth) based on the length of the wearing period. For one month this correction is approximately 0.97 (see Fig. 3). Thus our reported results would still

be too high by about 5% We cannot account for this discrepancy. Our dosimeter cards are calibrated using a Co-60 source whose exposure rate is determined by NBS calibrated ion chambers. Cards are enclosed in lucite 0.64 cm thick to establish charge-particle equilibrium. Cards in badges exposed on a five gallon water-filled polyethylene phantom give results within 1% of those in the lucite when the average of the two detectors is used as the dose determining parameter. Perhaps 5% agreement is acceptable. Second, the standard deviation is quite low, especially when one considers that we used no individual correction factors for this portion of the test. This was not always the case as will be noted later. Laboratory tests of the cards used for these tests showed that the standard deviation of the group was ± 3%. As will be seen later, we achieved better results than this in some parts of the test categories. We attribute this to the fact that all our x and gamma dose equivalents are the average of two detectors. Obviously using individual correction factors would not have improved our results appreciably. Thirdly, the magnitude of the exposure had little effect on the errors involved. This is probably true for most TLD systems. We consider 100 mR to be an infinite dose as far as errors are concerned. This suggests that error limits could be made more stringent for the lower intervals. However some systems may need the greater limits.

B. High-Energy X Rays

The results for the test for high-energy x rays are summarized in Table 2.

Table 2

TEST RESULTS FOR HIGH-ENERGY X RAYS

Dose Equiv. (mRem)	Ave. DE (mRem)	Eff. Energy	P(Ave)	Std. Dev. (S)	Error /P/+2S	Allowable Error
30-100S	66.9	208 keV	0.1160	0.1120	0.3401	1.8339
30-100D	66.9	"	0.1160	0.1120	0.3401	1.8339
101-300S	187.8	119 keV	-0.0018	0.0235	0.0487	1.0946
101-300D	187.8	"	-0.0018	0.0235	0.0487	1.0946
301-10000S	2868	58 keV	0.1356	0.0382	0.2119	0.5000
301-10000D	2756	"	0.1819	0.0392	0.2604	0.5000

Note the different test for shallow and deep dose equivalent as indicated by "S" and "D" in the DE column. Our badge generally cannot distinguish

the effective energy of the radiation in this energy range to assign a different deep and shallow dose equivalent. In most cases they are the same anyhow. Again we see that the standard deviations are quite small; again no individual correction factors were used. If we refer to the energy response of our badge in Fig. 4 we see that the under-response is about the same at 208 and 119 keV. Since we have a general over-response of about 10% as previously discussed, we would expect that the P(Ave) of the 208 and 119 keV irradiated badges would be about 0. This is true for the 119 keV exposures, but not for those at 208 keV. Since we use identical calibration spectra as the testing laboratory, the only reasonable explanation is a difference in phantom construction. All our calibrations were made using a rectangular, polyethylene, water filled phantom 33 cm x 23 cm x 23 cm thick. Exposures were determined with a free-air ion chamber.

C. Low-Energy X Rays

The results for the low-energy x rays are summarized in Table 3.

Table 3
TEST RESULTS FOR LOW-ENERGY X RAYS

Dose Equiv. (mRem)	Ave. DE (mRem)	Eff. Energy	P(Ave)	Std. Dev. (S)	Error /P/+2S	Allowable Error
150-300S	230.2	19 keV	-0.0257	0.0306	0.0868	0.9886
150-300D	71.2	"	-0.0273	0.0314	0.0901	1.7777
301-10000S	2508	"	-0.0408	0.0795	0.1998	0.5000
301-10000D	774	"	-0.0412	0.0797	0.2005	0.5391

In this case the ratio of the detector with the cadmium filter in front to the one with the filter behind was used to establish correction factors for the shallow and deep dose equivalents. These factors were 1.31 for the shallow DE and 0.41 for the deep DE applied to the average of the two detectors. These results are the first ones presented that were significantly different than those recorded in Test No. 1. At that time we had not calibrated for low-energy x rays and the average of the two detectors, with a slight correction, was reported for both shallow and deep dose equivalents. We realized this

would result in a large over-estimation of the deep dose equivalent and probably some under-estimation of the shallow dose equivalent.

D. Casualty Doses (Co-60, High-Energy X Ray)

The results for the casualty doses are summarized in Table 4. (Note in the appendix that we have made pen and ink changes to the data. The testing laboratory inadvertently recorded the badge number as the absorbed dose.)

Table 4
RESULTS FOR CASUALTY DOSES

Abs. Dose (Rad)	Ave. Dose (Rad)	Source	P(Ave)	Std. Dev. (S)	Error /P/+2S	Allowable Error
10-800	452.7	Co-60	0.0677	0.0254	0.1184	0.3000
10-800	394.3	136 keV	0.0963	0.0628	0.2219	0.3000

These results were obtained using individual correction factors for the detectors. We felt this to be necessary because these detectors had been used for the previous casualty tests and hence might have enhanced sensitivity (9). This enhancement turned out to be negligible, less than a few percent. Also corrections were made for supralinearity using the data in reference (6). During the first part of the test, no corrections were made for supralinearity resulting in an error of 0.4980 for x rays, and 3.3684 for Co-60. This latter result was mostly caused by two detector cards being placed in the wrong badges at NRL or the two badges being mixed up when exposed by the testing laboratory. Evidently such large errors were not infrequent and were partially attributed to reporting or computational errors by the testing laboratory (10). This was not true in our case since all our data handling is automated, and there were no typographical errors. We can not rule out that the dosimeter cards were put in the wrong badges. However, this seems unlikely since the procedure to guard against this was quite elaborate. For the second test we took even greater precautions to prevent such occurrences.

E. Neutron Exposures

The results of the neutron tests are summarized in Table 5:

Table 5

TEST RESULTS FOR Cf-252 NEUTRON

Dose Equiv. (mRem)	Ave. DE (mRem)	Source	P(Ave)	Std. Dev. (S)	Error /P/+2S	Allowable Error
100-300	205.6	Cf-252	0.1842	0.1697	0.5237	1.0461
301-5000	1980	"	-0.0707	0.0662	0.2030	0.5000

The neutron and the neutron plus gamma portions of the test proved the most diffucult for us. During the first part (Test No. 1) we did not use individual correction factors because we believed that the standard deviation for neutrons of the group of cards used for the test was the same as badges previously obtained from the manufacturer, about ± 3%. This turned out not to be the case, necessitating individual correction factors. An examination of the data in Table 5 reveals several interesting results. The most startling is an apparent non-linearity in response indicated by a P(Ave) of 0.1842 for the interval 100-300 mRem vs -0.0707 for the 301-5000 mRem interval. We have not previously observed this for neutrons and the data in Table 1 certainly does not indicate any non-linearity for gamma rays. Assuming the 301-5000 mRem interval to be the more reliable data, then our calibration procedure evidently results in an under-estimation of neutron DEs of approximately 17% (recall our over-all system response is approximately 10% high). We feel this comes from differences in phantoms and procedures. We make our calibration exposures in a concrete block laboratory room 4.7 meters wide, 7.1 meters long and 3.5 meters high, with the source and the center of the phantom 1.5 meters from the floor. Irradiations using Cf-252, are made with the center of the source a distance of 50 cm from the front surface of a rectangular, lucite, water-filled phantom having dimension of 60 cm x 30 cm x 23 cm thick. Corrections are made for neutrons scattered from the floor and walls. Without this correction we would report dose equivalents approximately 30% lower than those reported. We have determined that the scattered dose equivalent is less than 2% of the direct dose equivalent by exposing an ANPDR/70 Remeter at 40 cm and 50 cm. We assume the direct dose equivalent to vary inversely as the square of the source to detector distance while the scatter is constant. Not surprisingly, most of the scattered neutrons must be of lower energy to cause such an enhanced badge response. The increased standard deviation of our results in this category stem from two factors: First is the very nature of the dose equivalent equation (6). Since $(DE)_n$ is roughly dependent on $D_n(F)$ squared divided by $D_n(R)$ the expected error on $(DE)_n$ is more than twice the errors of $D_n(R)$ or $D_n(F)$. Contrast

this with the reduced error on $(DE)_\gamma$ resulting from the averaging of $D_\gamma(F)$ and $D_\gamma(R)$ (see reference (11). Hence, an albedo dosimeter which uses the ratios or products of multiple detectors automatically introduces errors at least three times those usually encountered for gamma radiation. The second factor is edge effects in the phantom which changes the ratio $D_n(F)/D_n(R)$ dependent on the dosimeter position on the phantom. We have found this to cause errors up to 50% in $(DE)_n$ between dosimeters irradiated at the top vs the bottom of a phantom similar to the one used by the testing laboratory.

F. Neutron Plus Gamma Exposures

This particular test provided two of the more interesting occurrences during the test: An almost certain mix-up of two badges, and the only failure of a dosimeter card during the test. The somewhat speculative results are shown in Table 6.

Table 6
RESULTS OF NEUTRON PLUS GAMMA EXPOSURES

Dose Equiv. (mRem)	Ave. DE (mRem)	Source	P(Ave)	Std. Dev. (S)	Error /P/+2S	Allowable Error
150-300	255.2	Co-60	-0.0141	0.1928	0.3998	1.0461
301-5000	2022	+Cf-252	0.0987	0.2058	0.5103	0.5000

The reader is referred to the Appendix pages 44-46 for the following discussion. When the dosimeters for the second month were processed dosimeter number 8 indicated a gamma DE of 1291 mRem and a neutron DE of 210 mRem, while dosimeter number 10 showed a gamma DE of 320 mRem and a neutron DE of 2756 mRem. Since these dosimeters were supposedly for the neutron or neutron plus gamma portion of the test, we assumed dosimeter number 8 had been mixed with the x-ray and gamma dosimeters, or had been improperly irradiated. We therefore voided the reading of dosimeter number 8. Since 320 mRem gamma is about the right gamma DE (certainly within the error of our system) to accompany a 2756 mRem neutron DE, we concluded that dosimeter number 10 had been exposed to neutrons only. Hence we reported only the neutron DE. It now seems obvious that the badges were given the correct gamma exposures but were interchanged or mixed up for the neutron exposures. We have made

this assumption and inked in what we believe to be the correct dose equivalents, including the gamma contribution from the Cf-252 neutron source. Measured 1291 gamma and 210 neutron vs postulated 1171 gamma and 231 neutron for dosimeter number 8 and measured 320 gamma and 2756 neutron vs postulated 311 gamma and 3024 neutron seems too close agreement to be accidental. Thus we have recalculated the average and standard deviation using the postulated exposures.

The reading for dosimeter number 18 is the only case in which a dosimeter card "failed" during either Test No. 1 or Test No. 2. A "failure" results when the dosimeter chip no longer adheres to the teflon in the dosimeter card and is no longer centered. This causes the loss of good thermal contact between the heater finger in the reader and the card. This results in some of the neutron plus gamma signal in the lower temperature integral to be moved up to the high temperature or neutron only integral, hence a large neutron signal. In this case $D_n(F)$ was increased making $D_n(F)/D_n(R)$ equal to approximately 10. The computer rejected this and inserted the limiting value of 4 (see Section IV) which of course still resulted in too large a neutron DE. It is possible to recalibrate a card which has failed in this fashion, but we hesitate to reduce a computed exposure. Hence, we used the correction factor obtained at the beginning of the test. Perhaps we should have voided this reading, but we feel there are better methods of dealing with such occurrences. See later recommendations. We point out that "failures" such as these have been rare, typically 1 per 1000 cards read. Omitting dosimeter number 18 would have reduced P to 0.0426, S to 0.1105 and /P/ + 2S to 0.2636.

VI. RESPONSE TO OTHER RADIATION CATEGORIES

The very simple NRL radiation badge, albeit a complicated dose determination procedure, was not designed to be able to measure all types of radiation without a knowledge of the radiation fields. Nevertheless, it would seem appropriate to project the performance we might expect to the other categories of radiation not tested.

A. Category IV, Beta

The NRL badge could distinguish a Sr-90 beta exposure from any of the other categories. Hence, based on its performance for gamma and x rays, it should easily be able to pass this category assuming proper calibration. The NRL badge is not a particularly

good beta dosimeter, however, because the detectors used are 0.9 mm thick; a thinner detector would be more appropriate. Being able to pass a performance test doesn't assure a good device. As an example, one can design an albedo dosimeter which could easily pass the neutron and neutron plus gamma portions of this test. It would not be a very good dosimeter for other spectra, however. One must guard against having performance tests that not only allow, but encourage the use of inferior dosimeters.

B. Category VI, Gamma Plus High-Energy X Ray

Our badge design would not be able to determine the exact proportions of mixed gamma and x-ray doses, but the dose equivalents determined should actually be about as accurate and precise as for gamma or x rays. This occurs because the dose equivalents are determined in exactly the same way for both types of radiation. Also the x-ray response is generally within 10% of the gamma response and in most cases is less. Since we have a general over-response of the system, mixing x-ray and gamma doses generally improves the average P more than 2S (standard deviation) is increased even if one assumes the worst case, all doses mixed 3:1. Thus the total error would be less than for gamma rays but greater than for x rays. In the exceptional case (MFG, 58 keV effective) where the x-ray response is 10% more than the gamma-ray response, the mixed results would be worse than the gamma ray results but better than for the x rays. In no case would the increased value of $/P/ + 2(S)$ exceed 0.02. Hence, we conclude the mixed gamma and x-ray exposures would be no problem for our badge.

C. Category VII, Gamma Plus Beta

The NRL badge could not distinguish gamma plus beta exposures from the other categories involved; hence, it would most likely assign the same dose equivalent for shallow and deep doses. The shallow dose equivalent would be too low, the deep dose equivalent too high. Our badge could not pass this category assuming doses mixed 3:1.

D. Other Possible Combinations

If we consider other possible combinations of exposures; beta plus low energy x ray, low-energy x ray plus high-energy x ray, etc., we conclude that the NRL badge would have difficulty with such mixtures. A badge with an additional detector shielded with a 1 cm tissue equivalent shield would perhaps provide enough additional information to make accurate dose equivalent determinations on such mixtures. The detector would most likely have to be fairly tissue

equivalent such as lithium fluoride or lithium borate. Even with one or two additional detectors, it may not be possible to design a badge which can accurately determine the shallow and deep dose equivalents for all possible combinations of radiations used in this test.

VII. RECOMMENDATIONS

A. Reduce the Number of Radiation Intervals

The test requires too much work and too many dosimeters. Perhaps two or three intervals for one radiation category is not excessive to determine how the response of a system varies with dose magnitude but this need not be repeated for other categories. One interval should be enough.

B. Eliminate the Casualty Dose Interval

Again this is to shorten the test. In case of an accident everyone should do good dosimetry with everything calibrated and re-calibrated, checked and rechecked, including probably a cross calibration with other radiation sources. This test is just not realistic. The likely performance can be inferred from the other intervals. A certification that instrumentation capable of covering this range should suffice. An exception would be a dosimeter designed only for casualty dose intervals. If this interval is retained the date of exposure should be given.

C. Reject the Worst Data

We recommend this to eliminate some of the problems described in the previous sections; mixed up dosimeters, and occasional catastrophic or routine failures of dosimeters. We suggest the two worst pieces of data in each interval be eliminated. Included would be lost readings, etc. It may be argued that mixing, or not mixing, dosimeters is also a part of performance but we have become convinced that the testing laboratory has as much trouble with this as the processors. Also, for any test where dosimeters are sent through the mails, one cannot rule out tampering. Several of our badges were opened and the cards reversed between the time they left NRL and were returned.

D. Change the Phantom Dimensions

The phantom used by the testing laboratory is too small to simultaneously irradiate six "albedo" neutron dosimeters. The edge effects are too great.

E. Change the Neutron Source

The neutron source used is probably not the most readily available for processors and is not, we believe, the most appropriate especially for "albedo" neutron dosimeters. We would recommend Am-Be or Pu-Be moderated by 2 - 4 cm of lucite.

F. Increase the Error Limits

We do not believe that most processors can readily pass these tests with presently used dosimetry devices. There are too many errors that cannot be easily reduced such as fading errors and errors due to mixed radiations. These can cause the standard deviation to increase as well as the average response. For the mixed categories we recommend that the error limit be determined by the formula $L = /P/ + 1.5\ S$. Also we feel that positive errors on P should be allowed without penalty, i.e., allow as much over-response of dosimetry devices as processors feel they can afford. Perhaps a factor of 2 should be an upper limit. Such an allowance might make an all-purpose dosimeter design more feasible and would probably be readily acceptable for processors whose average exposures are quite low.

VIII. CONCLUSIONS

We found our participation in this testing program enlightening and informative and more work than anticipated (we didn't really want to individually calibrate any dosimeters). The performance of the NRL dosimeter badge was better for x and gamma rays than in our own blind testing program, but worse for the neutron and neutron plus gamma portions. We attribute this to the different phantom used. The mixed doses and dosimeters, whether caused by us, the testing laboratory, or the mail service, was the most frustrating part of the test. We feel that a testing program such as this will do much to improve the dosimetry results of the processors who participate in it. It caused us to change some procedures, which in every case resulted in assigning lower dose equivalents to individuals. This may or may not be good. At least they should be more accurate.

IX. ACKNOWLEDGMENTS

The authors are indebted to Steve Gorbics and Al Nash of the Radiological Protection Staff for their contribution in the development

of the NRL dosimeter badge and for allowing us to use some of their data (Fig. 4) before publication. Steve also programmed the computer for the dose calculations. We also thank Dr. Margarete Ehrlich of NBS for a stimulating discussion of the performance testing program and for helpful information on the x-ray spectra used in these tests.

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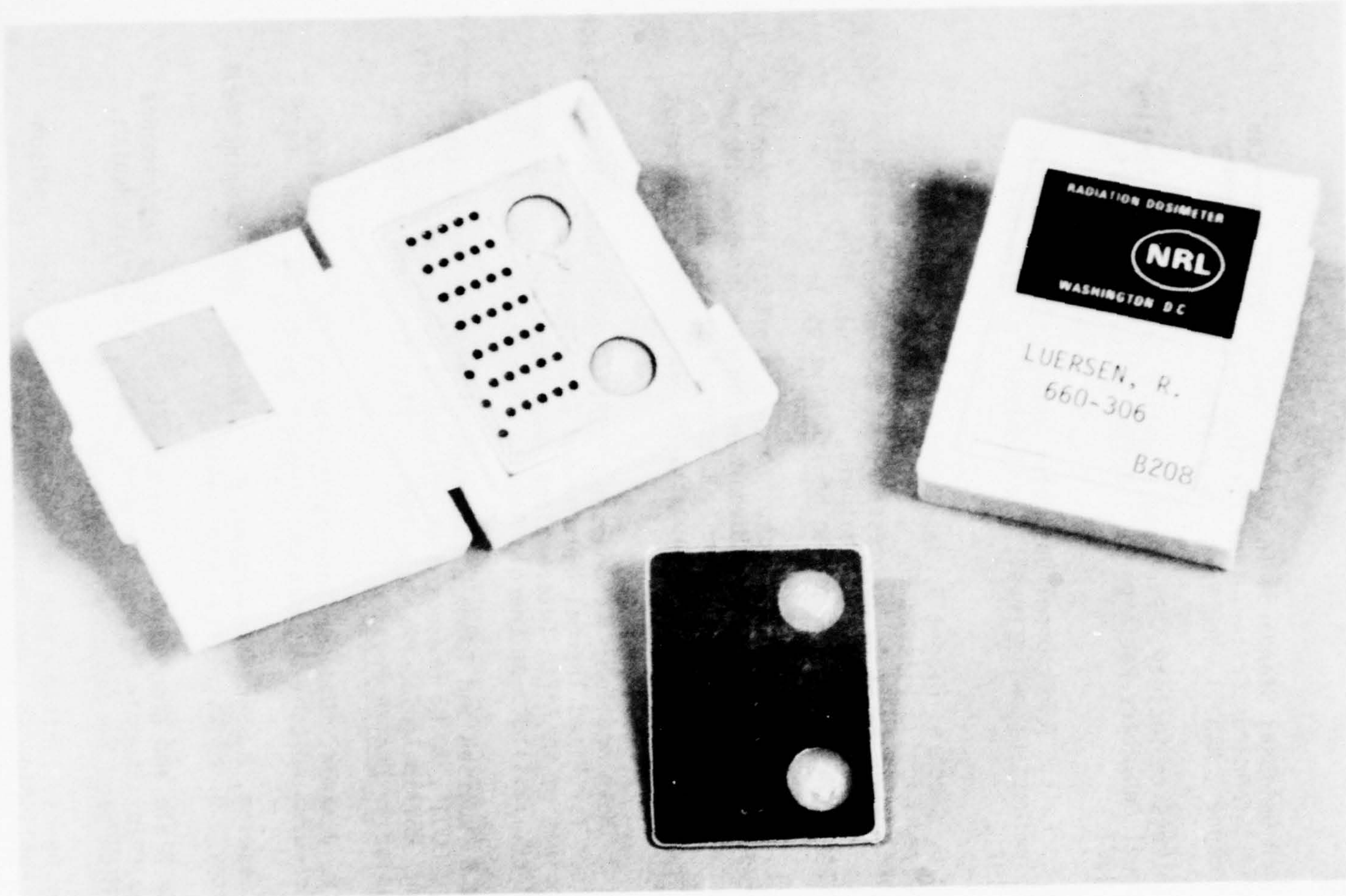

Fig. 1 The NRL radiation badge: upper left; opened showing the detector card in position; upper right, closed; bottom, the dosimeter card containing two LiF(TLD-600) detectors. The detectors are 3.2 mm × 3.2 mm × 0.9 mm thick.

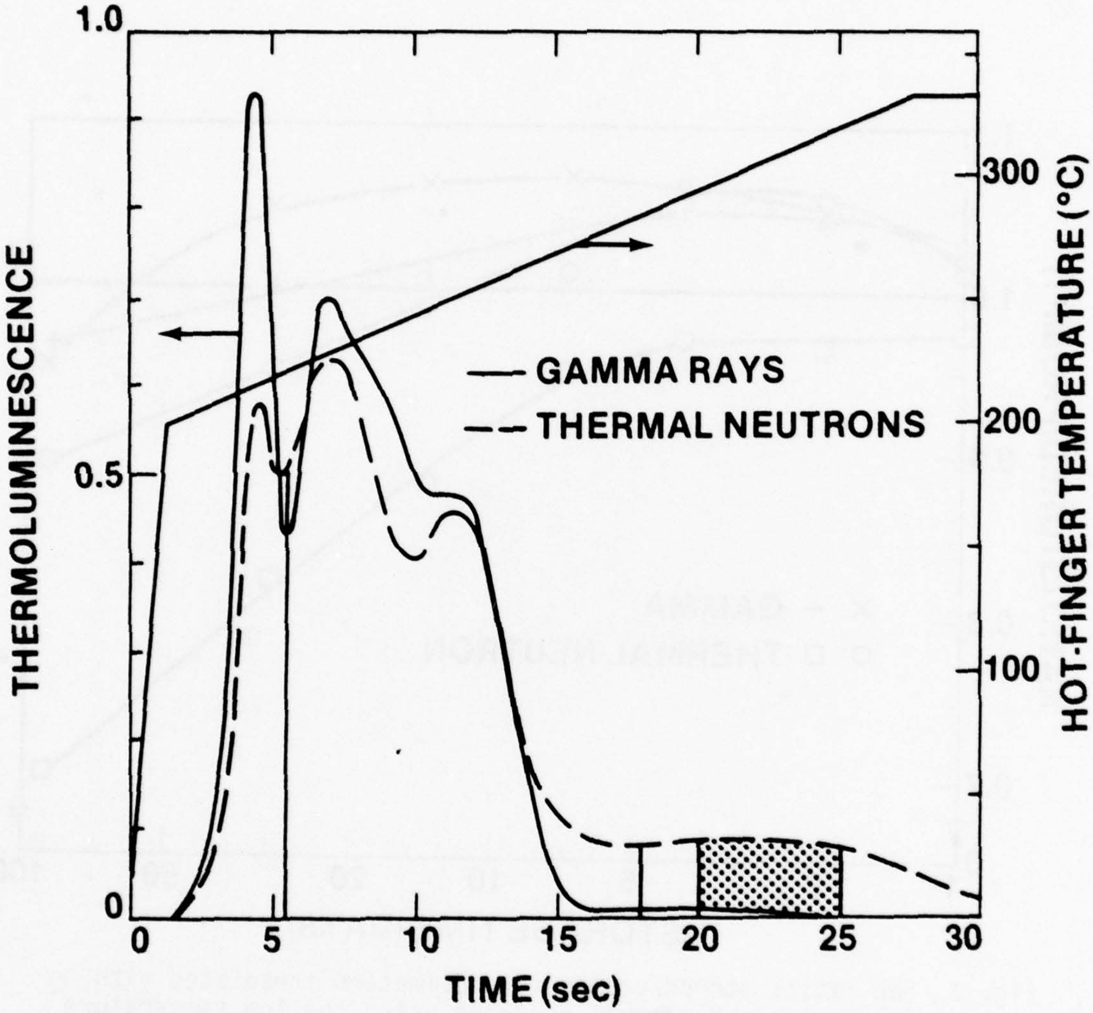

Fig. 2 Glow curves, thermoluminescence vs time; and readout heating schedule, hot-finger temperature vs time, for LiF(TLD-600) detectors that have been cycled, dosed and read 10 minutes thereafter in a Harshaw Model 2271 TL analyzer. For details see reference (6).

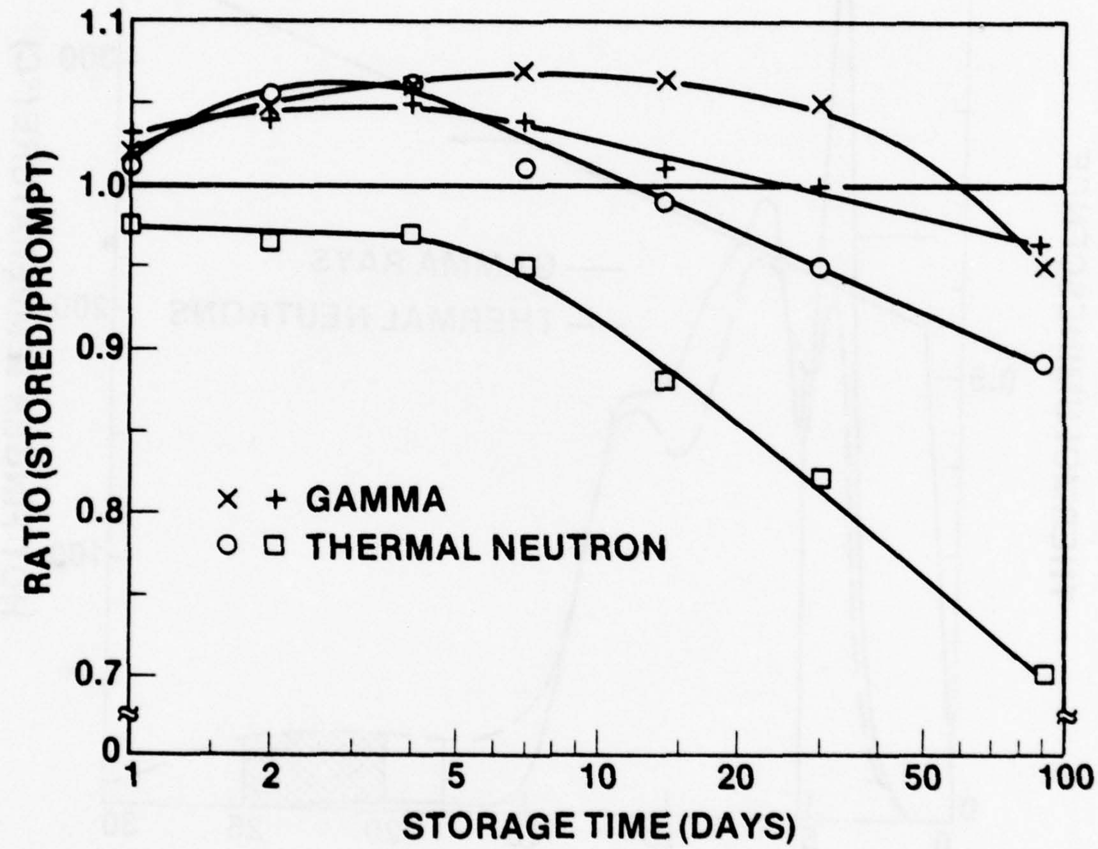

Fig. 3 The ratios stored/prompt for dosimeters irradiated with gamma rays and thermal neutrons using the low temperature integral shown in Fig. 2 as the dose determining parameter. The curves marked + and ■ were dosed before storage; those marked x and o were dosed after storage. The figure is taken from reference (7).

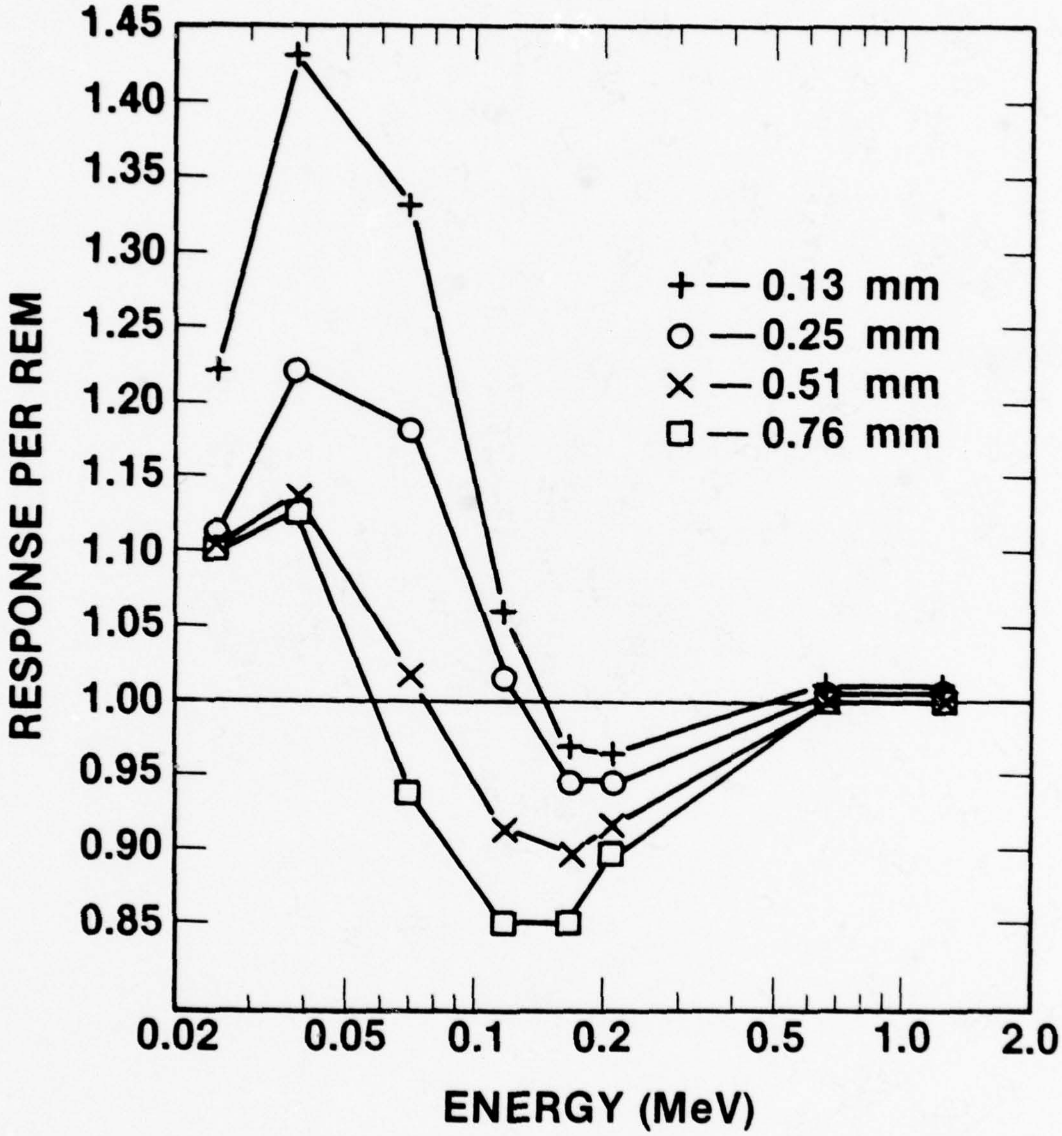

Fig. 4 The response of the NRL dosimeter badge per Rem (shallow dose equivalent) vs effective energy for several thickness of cadmium filters. The NRL badge uses 0.51 mm filters. Conversion from Roentgens to Rem was made using the data in reference (1). The figure is taken from reference (4).

APPENDIX

PERSONAL DOSIMETRY PERFORMANCE TESTING

A PILOT STUDY

SPONSORED BY :
U.S. NUCLEAR REGULATORY COMMISSION

CONDUCTED BY :
DEPT. OF ENVIRONMENTAL AND INDUSTRIAL HEALTH
SCHOOL OF PUBLIC HEALTH
UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

********** RESULTS OF TEST #2 **********

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : TLD

FOR EACH DOSIMETER, A PERFORMANCE INDEX IS CALCULATED BY :

$$P = (H^* - H)/H$$

WHERE : H = DELIVERED QUANTITY
H* = REPORTED QUANTITY

FOR EACH DEPTH OF EACH INTERVAL OF A CATEGORY, AN AVERAGE PERFORMANCE INDEX, (P AVERAGE), AND ITS STANDARD DEVIATION, S, ARE CALCULATED.

A PROCESSOR PASSES A CATEGORY IF, FOR EACH DEPTH OF EACH INTERVAL, THE ABSOLUTE VALUE OF (P AVERAGE) PLUS 2S IS LESS THAN OR EQUAL TO THE TOLERANCE LIMIT, L.

FOR CATEGORY I, INTERVAL 1, AND FOR CATEGORY II, INTERVAL 1, L = 0.3. FOR CATEGORY I, INTERVALS 2, 3, AND 4, L = 0.3 OR 6/SQRT(H AVERAGE), WHICHEVER IS LARGER. FOR ALL OTHER CATEGORIES, L = 0.5 OR 15/SQRT(H AVERAGE), WHICHEVER IS LARGER.

IF A DOSIMETER IS LOST, NOT REPORTED BY THE PROCESSOR, IRRADIATED IMPROPERLY, ETC., THE WORD VOID APPEARS NEXT TO THE DOSIMETER NUMBER. VOIDED DOSIMETERS ARE NOT INCLUDED IN THE PASS/FAIL CALCULATIONS.

CATEGORY I, GAMMA

INTERVAL 1, 10 - 800 RAD

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : TLD

SOURCE : COBALT-60 IRRADIATOR

IRRADIATION DISTANCE : SHOWN BELOW

DOSIMETER NUMBER	DATE IRRADIATED	EXPOS. RATE (R/MIN)	IRRA. TIME (MIN)	EXPOSURE (R)	IRRA. DIST. (CM)	DEEP ABSORBED DOSE, CX = 1.01 DELIV. (RAD)	REPORT. (RAD)	P=(H*-H)/H
58	2-20-79	54.54	3.820	208.34	100	210.	230.000	0.0952
36	2-20-79	54.54	9.860	537.76	100	543.	564.000	0.0387
43	2-20-79	54.54	13.860	755.92	100	763.	820.000	0.0747
70	2-20-79	54.54	12.920	704.66	100	712.	772.000	0.0843
7	3-20-79	53.99	11.830	638.70	100	645.	660.000	0.0233
18	3-20-79	53.99	10.400	561.50	100	567.	590.000	0.0406
10	3-20-79	53.99	1.960	105.82	100	107.	115.000	0.0748
62	4-18-79	53.43	3.570	190.75	100	193.	210.000	0.0881
46	4-18-79	53.43	6.140	328.06	100	331.	362.000	0.0937
41	4-18-79	53.43	8.450	451.48	100	456.	485.000	0.0636

P AVERAGE = 0.0677

S = 0.0254

H AVERAGE = 452.7

ABS(P AVERAGE) + 2S = 0.1184

L = 0.3000

********** PASS ************

CATEGORY I. GAMMA

INTERVAL 2, 30 - 100 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : TLD

SOURCE : COBALT-60 IRRADIATOR

IRRADIATION DISTANCE : SHOWN BELOW

DOSIMETER NUMBER	DATE IRRADIATED	EXPOS. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	IRRA. DIST. (CM)	DEEP DOSE DELIV. (MREM)	EQUIVALENT. REPORT. (MREM)	CX=1.01 P=(H*-H)/H
55	2-15-79	22.49	2.342	52.66	200	53.	60.	0.1321
40	2-15-79	22.49	4.208	94.65	200	96.	104.	0.0833
65	2-15-79	22.49	3.275	73.65	200	74.	82.	0.1081
35	3-23-79	22.20	3.572	79.29	200	80.	89.	0.1125
9	3-23-79	22.20	4.402	97.72	200	99.	102.	0.0303
22	3-23-79	22.20	1.497	33.23	200	34.	34.	0.0
28	3-23-79	22.20	1.715	38.07	200	38.	40.	0.0526
61	4-20-79	21.98	3.888	85.47	200	86.	91.	0.0581
56	4-20-79	21.98	1.953	42.93	200	43.	47.	0.0930
50	4-20-79	21.98	3.757	82.57	200	83.	99.	0.1928

P AVERAGE = 0.0863

S = 0.0549

H AVERAGE = 68.6

ABS(P AVERAGE) + 2S = 0.1962

L = 0.7244

********** PASS ***********

CATEGORY I. GAMMA

INTERVAL 3. 101 - 300 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : TLD

SOURCE : COBALT-60 IRRADIATOR

IRRADIATION DISTANCE : SHOWN BELOW

DOSIMETER NUMBER	DATE IRRADIATED	EXPOS. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	IRRA. DIST. (CM)	DEEP DOSE EQUIVALENT. CX=1.01 DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
54	2-26-79	88.73	2.725	241.79	100	244.	271.	0.1107
68	2-26-79	88.73	1.657	147.00	100	148.	161.	0.0878
49	2-26-79	88.73	2.675	237.35	100	240.	253.	0.0542
34	3-22-79	87.97	1.907	167.73	100	169.	187.	0.1065
15	3-22-79	87.97	2.023	177.99	100	180.	188.	0.0444
27	3-22-79	87.97	2.353	207.02	100	209.	213.	0.0191
8	3-22-79	87.97	1.738	152.92	100	154.	172.	0.1169
39	4-17-79	87.14	2.107	183.57	100	185.	213.	0.1514
52	4-17-79	87.14	1.558	135.79	100	137.	158.	0.1533
67	4-17-79	87.14	1.270	110.67	100	112.	130.	0.1607

P AVERAGE = 0.1005

S = 0.0488

H AVERAGE = 177.8

ABS(P AVERAGE) + 2S = 0.1982

L = 0.4500

********** PASS ************

CATEGORY I, GAMMA

INTERVAL 4, 301 - 10,000 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : TLD

SOURCE : COBALT-60 IRRADIATOR

IRRADIATION DISTANCE : SHOWN BELOW

DOSIMETER NUMBER	DATE IRRADIATED	EXPOS. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	IRRA. DIST. (CM)	DEEP DOSE EQUIVALENT. CX=1.01 DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
52	2-19-79	88.96	70.967	6313.19	100	6376.	6858.	0.0756
67	2-19-79	88.96	10.525	936.30	100	946.	1023.	0.0814
44	2-19-79	88.96	11.575	1029.71	100	1040.	1083.	0.0413
37	2-19-79	88.96	7.958	707.97	100	715.	803.	0.1231
5	3-27-79	87.81	57.050	5009.56	100	5060.	5482.	0.0834
21	3-27-79	87.81	10.005	878.54	100	887.	974.	0.0981
33	3-27-79	87.81	7.890	692.82	100	700.	780.	0.1143
69	4-11-79	87.33	54.350	4746.38	100	4794.	5523.	0.1521
51	4-11-79	87.33	6.000	523.98	100	529.	592.	0.1191
57	4-11-79	87.33	102.667	8965.84	100	9056.	10004.	0.1047

P AVERAGE = 0.0993

S = 0.0307

H AVERAGE = 3010.3

ABS(P AVERAGE) + 2S = 0.1607

L = 0.3000

********** PASS ************

CATEGORY II. HIGH-ENERGY X RAY

INTERVAL 1. 10 - 800 RAD

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : TLD

NBS TECHNIQUE : MFK

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (R/MIN)	IRRA. TIME (MIN)	EXPOSURE (R)	DEEP ABSORBED DOSE, CX = 1.33 DELIV. (RAD)	REPORT. (RAD)	P=(H*-H)/H
53	2-23-79	8.83	46.580	411.30	547.	605.000	0.1060
46	2-23-79	8.83	20.100	177.48	236.	268.000	0.1356
62	2-23-79	8.83	3.830	33.82	45.	55.000 ~~62.000~~	0.2222 0.3778
41	2-24-79	8.78	50.400	442.51	589.	615.000	0.0441
30	3-26-79	10.83	48.110	521.03	693.	685.000	-0.0115
29	3-26-79	10.83	7.140	77.33	103.	115.000	0.1165
1	3-26-79	10.83	52.330	566.73	754.	795.000	0.0544
36	4-25-79	10.54	32.660	344.24	458.	492.000	0.0742
70	4-25-79	10.54	25.270	266.35	354.	387.000	0.0932
43	4-25-79	10.54	11.710	123.42	164.	185.000	0.1280

P AVERAGE = .0963 0.1118

S = 0.0628 0.1035

H AVERAGE = 394.3

ABS(P AVERAGE) + 2S = 0.2219 ~~0.3184~~

L = 0.3000

********** ~~FAIL~~ **********

PASS

CATEGORY II. HIGH-ENERGY X RAY

INTERVAL 2. 30 - 100 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : TLD

NBS TECHNIQUE : HFK

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	SHALLOW DOSE EQUIV., CX=1.260 DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
69	2-21-79	20.44	1.680	34.34	43.	59.	0.3721
56	2-21-79	20.44	2.230	45.58	57.	70.	0.2281
47	2-21-79	20.44	3.400	69.50	88.	97.	0.1023
32	3-23-79	20.46	3.195	65.37	82.	89.	0.0854
17	3-23-79	20.46	3.815	78.05	98.	105.	0.0714
12	3-23-79	20.46	1.820	37.24	47.	49.	0.0426
26	3-23-79	20.46	1.230	25.17	32.	33.	0.0313
49	4-25-79	21.30	2.450	52.18	66.	77.	0.1667
44	4-25-79	21.30	2.710	57.72	73.	73.	0.0
66	4-25-79	21.30	3.100	66.03	83.	88.	0.0602

P AVERAGE = 0.1160

S = 0.1120

H AVERAGE = 66.9

ABS(P AVERAGE) + 2S = 0.3401

L = 1.8339

*********** PASS **********

CATEGORY II. HIGH-ENERGY X RAY

INTERVAL 2. 30 - 100 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : TLD

NBS TECHNIQUE : HFK

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DEEP DOSE EQUIVALENT, CX=1.260 DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
69	2-21-79	20.44	1.680	34.34	43.	59.	0.3721
56	2-21-79	20.44	2.230	45.58	57.	70.	0.2281
47	2-21-79	20.44	3.400	69.50	88.	97.	0.1023
32	3-23-79	20.46	3.195	65.37	82.	89.	0.0854
17	3-23-79	20.46	3.815	78.05	98.	105.	0.0714
12	3-23-79	20.46	1.820	37.24	47.	49.	0.0426
26	3-23-79	20.46	1.230	25.17	32.	33.	0.0313
49	4-25-79	21.30	2.450	52.18	66.	77.	0.1667
44	4-25-79	21.30	2.710	57.72	73.	73.	0.0
66	4-25-79	21.30	3.100	66.03	83.	88.	0.0602

P AVERAGE = 0.1160

S = 0.1120

H AVERAGE = 66.9

ABS(P AVERAGE) + 2S = 0.3401

L = 1.8339

*********** PASS **********

CATEGORY II. HIGH-ENERGY X RAY

INTERVAL 3. 101 - 300 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : TLD

NBS TECHNIQUE : HFG

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	SHALLOW DOSE EQUIV., CX=1.350 DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
63	2-20-79	62.55	1.860	116.34	157.	155.	-0.0127
59	2-20-79	62.55	1.305	81.63	110.	115.	0.0455
48	2-20-79	62.55	2.950	184.52	249.	254.	0.0201
31	3-21-79	65.60	2.040	133.82	181.	183.	0.0110
23	3-21-79	65.60	1.520	99.71	135.	134.	-0.0074
16	3-21-79	65.60	1.970	129.23	174.	172.	-0.0115
11	3-21-79	65.60	2.310	151.54	205.	199.	-0.0293
56	4-24-79	66.13	2.400	158.71	214.	216.	0.0093
45	4-24-79	66.13	3.280	216.91	293.	284.	-0.0307
65	4-24-79	66.13	1.790	118.37	160.	158.	-0.0125

P AVERAGE = -0.0018

S = 0.0235

H AVERAGE = 187.8

ABS(P AVERAGE) + 2S = 0.0487

L = 1.0946

*********** PASS **********

CATEGORY II. HIGH-ENERGY X RAY

INTERVAL 3. 101 - 300 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : TLD

NBS TECHNIQUE : HFG

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DEEP DOSE DELIV. (MREM)	EQUIVALENT, CX=1.350 REPORT. (MREM)	P=(H*-H)/H
63	2-20-79	62.55	1.860	116.34	157.	155.	-0.0127
59	2-20-79	62.55	1.305	81.63	110.	115.	0.0455
48	2-20-79	62.55	2.950	184.52	249.	254.	0.0201
31	3-21-79	65.60	2.040	133.82	181.	183.	0.0110
23	3-21-79	65.60	1.520	99.71	135.	134.	-0.0074
16	3-21-79	65.60	1.970	129.23	174.	172.	-0.0115
11	3-21-79	65.60	2.310	151.54	205.	199.	-0.0293
56	4-24-79	66.13	2.400	158.71	214.	216.	0.0093
45	4-24-79	66.13	3.280	216.91	293.	284.	-0.0307
65	4-24-79	66.13	1.790	118.37	160.	158.	-0.0125

P AVERAGE = -0.0018

S = 0.0235

H AVERAGE = 187.8

ABS(P AVERAGE) + 2S = 0.0487

L = 1.0946

********** PASS **********

CATEGORY II. HIGH-ENERGY X RAY

INTERVAL 4. 301 - 10,000 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : TLD

NBS TECHNIQUE : MFG

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	SHALLOW DOSE EQUIV., CX=1.280 DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
51	2-14-79	877.20	5.090	4464.95	5715.	6530.	0.1426
45	2-13-79	105.20	3.110	327.17	419.	464.	0.1074
64	2-14-79	877.20	2.355	2065.81	2644.	3069.	0.1607
60	2-13-79	105.20	3.490	367.15	470.	550.	0.1702
25	3-21-79	860.30	6.300	5419.89	6937.	7887.	0.1369
6	3-21-79	860.30	5.930	5101.58	6530.	7390.	0.1317
14	3-19-79	102.90	5.685	584.99	749.	866.	0.1562
68	4-24-79	896.30	3.690	3307.35	4233.	5054.	0.1940
47	4-24-79	73.27	3.820	279.89	358.	386.	0.0782
55	4-24-79	73.27	6.670	488.71	626.	675.	0.0783

P AVERAGE = 0.1356

S = 0.0382

H AVERAGE = 2868.1

ABS(P AVERAGE) + 2S = 0.2119

L = 0.5000

*********** PASS **********

CATEGORY II. HIGH-ENERGY X RAY

INTERVAL 4. 301 - 10.000 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : TLD

NBS TECHNIQUE : MFG

IRRADIATION DISTANCE : 100 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DEEP DOSE EQUIVALENT. CX=1.230 DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
51	2-14-79	877.20	5.090	4464.95	5492.	6530.	0.1890
45	2-13-79	105.20	3.110	327.17	402.	464.	0.1542
64	2-14-79	877.20	2.355	2065.81	2541.	3069.	0.2078
60	2-13-79	105.20	3.490	367.15	452.	550.	0.2168
25	3-21-79	860.30	6.300	5419.89	6666.	7887.	0.1832
6	3-21-79	860.30	5.930	5101.58	6275.	7390.	0.1777
14	3-19-79	102.90	5.685	584.99	720.	866.	0.2028
68	4-24-79	896.30	3.690	3307.35	4068.	5054.	0.2424
47	4-24-79	73.27	3.820	279.89	344.	386.	0.1221
55	4-24-79	73.27	6.670	488.71	601.	675.	0.1231

P AVERAGE = 0.1819

S = 0.0392

H AVERAGE = 2756.1

ABS(P AVERAGE) + 2S = 0.2604

L = 0.5000

*********** PASS **********

CATEGORY III. LOW-ENERGY X RAY

INTERVAL 1. 150 - 300 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : TLD

NBS TECHNIQUE : L-G

IRRADIATION DISTANCE : 200 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	SHALLOW DOSE EQUIV., CX=0.810 DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
57	2-26-79	114.50	1.900	217.55	176.	163.	-0.0739
66	2-26-79	114.50	2.920	334.34	271.	264.	-0.0258
39	2-26-79	114.50	2.260	258.77	210.	203.	-0.0333
50	2-26-79	114.50	2.780	318.31	258.	260.	0.0078
2	3-13-79	116.80	2.660	310.69	252.	236.	-0.0635
13	3-13-79	116.80	2.770	323.54	262.	247.	-0.0573
24	3-13-79	116.80	3.010	351.57	285.	281.	-0.0140
48	4-28-79	116.00	2.510	291.16	236.	234.	-0.0085
59	4-28-79	116.00	1.830	212.28	172.	174.	0.0116
60	4-28-79	116.00	1.920	222.72	180.	180.	0.0

P AVERAGE = -0.0257

S = 0.0306

H AVERAGE = 230.2

ABS(P AVERAGE) + 2S = 0.0868

L = 0.9886

*********** PASS **********

CATEGORY III, LOW-ENERGY X RAY

INTERVAL 1, 150 - 300 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : TLD

NBS TECHNIQUE : L-G

IRRADIATION DISTANCE : 200 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DEEP DOSE EQUIVALENT, CX=0.250 DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
57	2-26-79	114.50	1.900	217.55	54.	50.	-0.0741
66	2-26-79	114.50	2.920	334.34	84.	81.	-0.0357
39	2-26-79	114.50	2.260	258.77	65.	63.	-0.0308
50	2-26-79	114.50	2.780	318.31	80.	80.	0.0
2	3-13-79	116.80	2.660	310.69	78.	73.	-0.0641
13	3-13-79	116.80	2.770	323.54	81.	76.	-0.0617
24	3-13-79	116.80	3.010	351.57	88.	87.	-0.0114
48	4-28-79	116.00	2.510	291.16	73.	72.	-0.0137
59	4-28-79	116.00	1.830	212.28	53.	54.	0.0189
60	4-28-79	116.00	1.920	222.72	56.	56.	0.0

P AVERAGE = -0.0273

S = 0.0314

H AVERAGE = 71.2

ABS(P AVERAGE) + 2S = 0.0901

L = 1.7777

*********** PASS **********

CATEGORY III, LOW-ENERGY X RAY

INTERVAL 2, 301 - 10,000 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : TLD

NBS TECHNIQUE : L-G

IRRADIATION DISTANCE : 200 CM

		IRRA.	IRRA.		SHALLOW DOSE EQUIV., CX=0.810		
DOSIMETER NUMBER	DATE IRRADIATED	RATE (MR/MIN)	TIME (MIN)	EXPOSURE (MR)	DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
42	2-26-79	286.40	18.150	5198.16	4211.	3153.	-0.2512
38	2-26-79	286.40	37.460	10728.54	8690.	8825.	0.0155
61	2-26-79	286.40	2.910	833.42	675.	684.	0.0133
19	3-14-79	288.60	1.660	479.08	388.	361.	-0.0696
4	3-14-79	288.60	8.270	2386.72	1933.	1916.	-0.0088
20	3-14-79	288.60	1.870	539.68	437.	411.	-0.0595
64	4-29-79	288.80	2.150	620.92	503.	510.	0.0139
40	4-29-79	288.80	29.900	8635.12	6994.	6824.	-0.0243
37	4-29-79	288.80	3.460	999.25	809.	797.	-0.0148
63	4-29-79	288.80	1.870	540.06	437.	427.	-0.0229

P AVERAGE = -0.0408

S = 0.0795

H AVERAGE = 2507.7

ABS(P AVERAGE) + 2S = 0.1998

L = 0.5000

********** PASS **********

CATEGORY III, LOW-ENERGY X RAY

INTERVAL 2, 301 - 10,000 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : TLD

NBS TECHNIQUE : L-G

IRRADIATION DISTANCE : 200 CM

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DEEP DOSE EQUIVALENT, CX=0.250 DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
42	2-26-79	286.40	18.150	5198.16	1300.	974.	-0.2508
38	2-26-79	286.40	37.460	10728.54	2682.	2726.	0.0164
61	2-26-79	286.40	2.910	833.42	208.	211.	0.0144
19	3-14-79	288.60	1.660	479.08	120.	111.	-0.0750
4	3-14-79	288.60	8.270	2386.72	597.	592.	-0.0084
20	3-14-79	288.60	1.870	539.68	135.	127.	-0.0593
64	4-29-79	288.80	2.150	620.92	155.	157.	0.0129
40	4-29-79	288.80	29.900	8635.12	2159.	2108.	-0.0236
37	4-29-79	288.80	3.460	999.25	250.	246.	-0.0160
63	4-29-79	288.80	1.870	540.06	135.	132.	-0.0222

P AVERAGE = -0.0412

S = 0.0797

H AVERAGE = 774.1

ABS(P AVERAGE) + 2S = 0.2005

L = 0.5391

*********** PASS **********

CATEGORY V. NEUTRON

INTERVAL 1. 100 - 300 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : ALBEDO

SOURCE : CALIFORNIUM-252

IRRADIATION DISTANCE : SHOWN BELOW

NOTE : DELIVERED DOSE EQUIVALENT INCLUDES THE
ROOM RETURN (SCATTER) CORRECTION FACTOR
SHOWN BELOW

DOSIMETER NUMBER	DATE IRRADIATED	DOSE EQ. RATE (MREM/MIN)	IRRA. TIME (MIN)	IRRA. DIST. (CM)	SCATTER C.F.	DEEP DOSE EQUIVALENT DELIV. (MREM)	DEEP DOSE EQUIVALENT REPORT. (MREM)	P=(H*-H)/H
29	2-21-79	78.45	1.385	50	1.040	113.	158.	0.3982
24	2-21-79	78.45	2.628	50	1.040	214.	281.	0.3131
18	2-21-79	78.45	3.732	50	1.040	304.	368.	0.2105
22	2-21-79	78.45	2.386	50	1.040	195.	239.	0.2256
6	3-13-79	77.33	2.070	50	1.040	166.	211.	0.2711
2	3-13-79	77.33	3.535	50	1.040	284.	300.	0.0563
1	3-13-79	77.33	3.400	50	1.040	273.	277.	0.0147
17	4-26-79	74.93	2.588	50	1.040	202.	254.	0.2574
30	4-26-79	74.93	1.540	50	1.040	120.	99.	-0.1750
21	4-26-79	74.93	2.368	50	1.040	185.	235.	0.2703

P AVERAGE = 0.1842

S = 0.1697

H AVERAGE = 205.6

ABS(P AVERAGE) + 2S = 0.5237

L = 1.0461

********** PASS ************

CATEGORY V. NEUTRON

INTERVAL 2. 301 - 5.000 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : ALBEDO

SOURCE : CALIFORNIUM-252

IRRADIATION DISTANCE : SHOWN BELOW

NOTE : DELIVERED DOSE EQUIVALENT INCLUDES THE
ROOM RETURN (SCATTER) CORRECTION FACTOR
SHOWN BELOW

DOSIMETER NUMBER	DATE IRRADIATED	DOSE EQ. RATE (MREM/MIN)	IRRA. TIME (MIN)	IRRA. DIST. (CM)	SCATTER C.F.	DEEP DOSE EQUIVALENT DELIV. (MREM)	REPORT. (MREM)	P=(H*-H)/H
27	2-25-79	78.22	49.600	50	1.040	4035.	3914.	-0.0300
25	2-25-79	78.22	4.452	50	1.040	362.	356.	-0.0166
17	2-25-79	78.22	23.550	50	1.040	1916.	1748.	-0.0877
30	2-25-79	78.22	11.780	50	1.040	958.	915.	-0.0449
7	3-22-79	76.83	57.660	50	1.040	4607.	3782.	-0.1791
4	3-22-79	76.83	10.350	50	1.040	827.	697.	-0.1572
3	3-22-79	76.83	39.710	50	1.040	3173.	2744.	-0.1352
24	4-18-79	75.36	11.330	50	1.040	888.	843.	-0.0507
19	4-18-79	75.36	32.000	50	1.040	2508.	2552.	0.0175
28	4-18-79	75.36	6.700	50	1.040	525.	513.	-0.0229

P AVERAGE = -0.0707

S = 0.0662

H AVERAGE = 1979.9

ABS(P AVERAGE) + 2S = 0.2030

L = 0.5000

********** PASS ***********

CATEGORY VIII, GAMMA COMPONENT
OF NEUTRON PLUS GAMMA

INTERVAL 1, 150 - 300 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : ALBEDO

SOURCE : COBALT-60 IRRADIATOR

IRRADIATION DISTANCE : 100 CM

NOTE : DELIVERED DOSE EQUIVALENT INCLUDES A GAMMA-RAY CONTRIBUTION FROM THE CF-252 SOURCE EQUAL TO 7.633 PERCENT OF THE NEUTRON DOSE EQUIVALENT

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DELIVERED DOSE EQUIVALENT SHALLOW CX=1.01 (MREM)	DELIVERED DOSE EQUIVALENT DEEP CX=1.01 (MREM)
21	2- 6-79	89.37	0.708	63.30	75.	75.
19	2- 6-79	89.37	1.370	122.44	138.	138.
26	2- 6-79	89.37	0.922	82.37	98.	98.
9	3-10-79	88.35	1.888	166.83	173.	173.
5	3-10-79	88.35	0.713	63.02	75.	75.
14	3-10-79	88.35	1.337	118.09	123.	123.
11	3-10-79	88.35	0.880	77.75	92.	92.
16	4-10-79	87.37	1.568	137.03	142.	142.
29	4-10-79	87.37	0.608	53.15	63.	63.
20	4-10-79	87.37	1.977	172.70	179.	179.

CATEGORY VIII, NEUTRON COMPONENT OF NEUTRON PLUS GAMMA

INTERVAL 1, 150 - 300 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : ALBEDO

SOURCE : CALIFORNIUM-252

IRRADIATION DISTANCE : SHOWN BELOW

NOTE : DELIVERED DOSE EQUIVALENT INCLUDES THE ROOM RETURN (SCATTER) CORRECTION FACTOR SHOWN BELOW

DOSIMETER NUMBER	DATE IRRADIATED	DOSE EQ. RATE (MREM/MIN)	IRRA. TIME (MIN)	IRRA. DIST. (CM)	SCATTER C.F.	DELIVERED DOSE EQUIVALEN SHALLOW (MREM)	DEEP (MREM)
21	2-25-79	78.22	2.000	50	1.040	163.	163.
19	2-25-79	78.22	2.516	100	1.170	230.	230.
26	2-25-79	78.22	2.623	50	1.040	213.	213.
9	3-22-79	19.25	3.450	100	1.170	78.	78.
5	3-22-79	76.83	2.070	50	1.040	165.	165.
14	3-22-79	19.25	2.446	100	1.170	55.	55.
11	3-22-79	76.83	2.543	50	1.040	203.	203.
16	4-26-79	18.73	2.937	100	1.170	64.	64.
29	4-26-79	74.93	1.811	50	1.040	141.	141.
20	4-26-79	18.73	3.737	100	1.170	82.	82.

INTERVAL 1, 150 - 300 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : ALBEDO

DOSIMETER NUMBER	TOTAL DEEP DOSE EQUIVALENT DELIVERED (MREM)	REPORTED (MREM)	P=(H'-H)/H
21	238.	272.	0.1429
19	368.	198.	-0.4620
26	311.	304.	-0.0225
9	251.	252.	0.0040
5	240.	228.	-0.0500
14	178.	200.	0.1236
11	295.	267.	-0.0949
16	206.	202.	-0.0194
29	204.	197.	-0.0343
20	261.	332.	0.2720

P AVERAGE = -0.0141

S = 0.1928

H AVERAGE = 255.2

ABS(P AVERAGE) + 2S = 0.3998

L = 0.9390

*********** PASS **********

CATEGORY VIII, GAMMA COMPONENT OF NEUTRON PLUS GAMMA

INTERVAL 2, 301 - 5,000 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : ALBEDO

SOURCE : COBALT-60 IRRADIATOR

IRRADIATION DISTANCE : 100 CM

NOTE : DELIVERED DOSE EQUIVALENT INCLUDES A GAMMA-RAY CONTRIBUTION FROM THE CF-252 SOURCE EQUAL TO 7.033 PERCENT OF THE NEUTRON DOSE EQUIVALENT

DOSIMETER NUMBER	DATE IRRADIATED	IRRA. RATE (MR/MIN)	IRRA. TIME (MIN)	EXPOSURE (MR)	DELIVERED DOSE EQUIVALENT SHALLOW CX=1.01 (MREM)	DELIVERED DOSE EQUIVALENT DEEP CX=1.01 (MREM)
20	2- 8-79	89.31	15.092	1347.84	1589.	1589.
23	2- 8-79	89.31	2.512	224.32	266.	266.
28	2- 8-79	89.31	27.550	2460.49	2554.	2554.
13	3-12-79	88.28	7.138	630.17	654.	654.
8 VOID	3-12-79	88.28	12.955	1143.67	(1171) 1360.	(1171) 1360.
10	3-12-79	88.28	1.102	97.26	(311) 114.	(311) 114.
15	3-12-79	88.28	12.325	1088.05	1296.	1296.
26	4- 9-79	87.40	3.403	297.45	309.	309.
18	4- 9-79	87.40	13.173	1151.35	1213.	1213.
27	4- 9-79	87.40	2.707	236.56	284.	284.

CATEGORY VIII, NEUTRON COMPONENT
OF NEUTRON PLUS GAMMA

INTERVAL 2, 301 - 5,000 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 36

TYPE OF DOSIMETER : ALBEDO

SOURCE : CALIFORNIUM-252

IRRADIATION DISTANCE : SHOWN BELOW

NOTE : DELIVERED DOSE EQUIVALENT INCLUDES THE
ROOM RETURN (SCATTER) CORRECTION FACTOR
SHOWN BELOW

DOSIMETER NUMBER	DATE IRRADIATED	DOSE EQ. RATE (MREM/MIN)	IRRA. TIME (MIN)	IRRA. DIST. (CM)	SCATTER C.F.	DELIVERED DOSE EQUIVALEN SHALLOW (MREM)	DEEP (MREM)
20	2-24-79	78.28	41.380	50	1.040	3369.	3369.
23	2-24-79	78.28	7.160	50	1.040	583.	583.
28	2-24-79	78.28	12.560	50	1.040	1023.	1023.
13	3-27-79	76.56	3.323	50	1.040	265.	265.
8 VOID	3-27-79	76.56	37.980	50	1.040	(231) 3024.	(231) 3024.
10	3-27-79	76.56	2.897	50	1.040	(3024) 231.	(3024) 231.
15	3-27-79	76.56	36.510	50	1.040	2907.	2907.
26	4-19-79	75.36	1.603	50	1.040	126.	126.
18	4-19-79	75.36	9.525	50	1.040	747.	747.
27	4-19-79	75.36	8.486	50	1.040	665.	665.

INTERVAL 2. 301 - 5.000 MREM

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 38

TYPE OF DOSIMETER : ALBEDO

DOSIMETER NUMBER	TOTAL DEEP DOSE EQUIVALENT DELIVERED (MREM)	REPORTED (MREM)	P=(H*-H)/H
20	4958.	5306.	0.0702
23	849.	967.	0.1390
28	3577.	3811.	0.0654
13	919.	957.	0.0413
8 VOID	(1402) 4384.	(1501) 0.	(0.0761) -1.0000
16	(3335) 345.	(3076) 2756.	(-0.0777) 6.9884
15	4203.	4556.	0.0840
26	435.	510.	0.1724
18	1960.	3143.	0.6036
27	949.	771.	-0.1876

P AVERAGE = 0.0987 0.8863

S = 0.2058 2.2477

H AVERAGE = 2021.7

ABS(P AVERAGE) + 2S = 0.5103 5.4817

L = 0.5000

*********** FAIL **********

********** SUMMARY OF RESULTS **********

PROCESSOR NAME : NAVAL RESEARCH

PROCESSOR CODE NO. : 36

TYPE OF DOSIMETER : TLD

CATEGORY I.	GAMMA	: PASS
CATEGORY II.	HIGH-ENERGY X RAY	: ~~FAIL~~ PASS
CATEGORY III.	LOW-ENERGY X RAY	: PASS
CATEGORY IV.	BETA	: **
CATEGORY V.	NEUTRON	: PASS
CATEGORY VI.	GAMMA PLUS HIGH-ENERGY X RAY	: **
CATEGORY VII.	GAMMA PLUS BETA	: **
CATEGORY VIII.	GAMMA PLUS NEUTRON	: FAIL

** = PROCESSOR DID NOT PARTICIPATE IN THIS CATEGORY